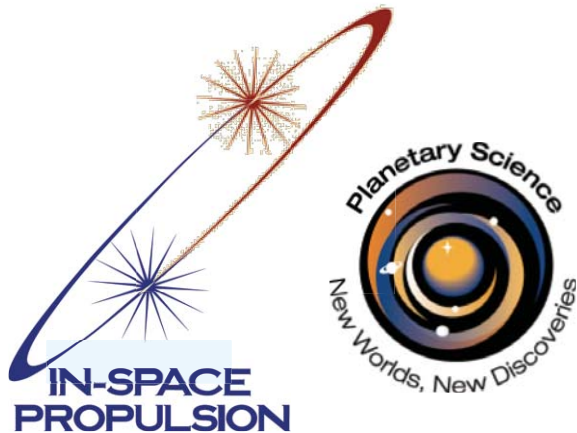


Status of Propulsion Technology Development under the NASA In-space Propulsion Technology Program



David Anderson, Hani Kamhawi, Mike Patterson, John Dankanich, Eric Pencil, and Luis Pinero
Space Propulsion 2014, Cologne, Germany
May 21, 2014

NASA's In-Space Propulsion Technology (ISPT) Program



NASA's ISPT Program develops critical propulsion, entry vehicle, and other spacecraft and platform subsystem technologies to enable or significantly enhance future planetary science missions.

- *Enable access to more challenging and interesting science destinations or benefit future robotic science missions*
- *By significantly reducing travel times to distant bodies, increasing scientific payload capability, or reducing mission cost and risk.*
- *The current ISPT focus is TRL 3-6+ product development.*

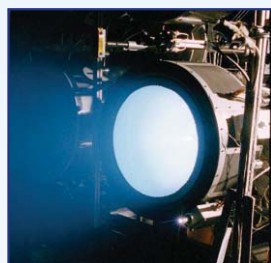


Propulsion System Technologies

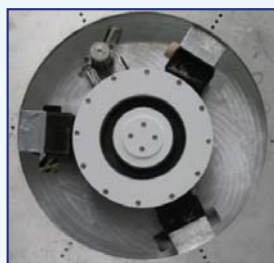
AMBR High-Temp Rocket Engine



7 kW NEXT Ion Propulsion System



4 kW HIVHAC Thruster & Hall Propulsion System

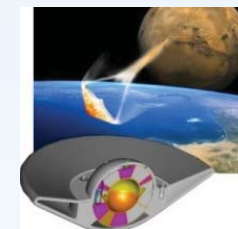
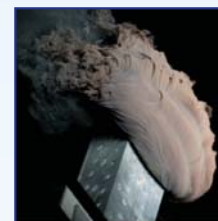


Entry Vehicle Technologies

Aerocapture



Multi-Mission Earth Entry Vehicle

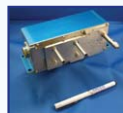


Spacecraft Bus & Sample Return Technologies

Mars Ascent Vehicle



Spacecraft Bus Components

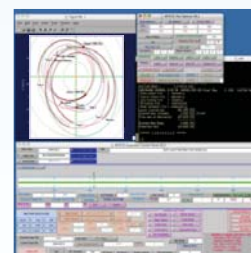


Extreme Environments

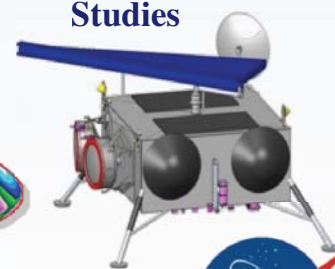
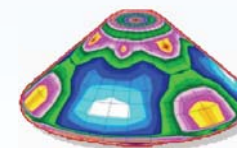


Systems & Mission Studies

Mission Analysis Tools



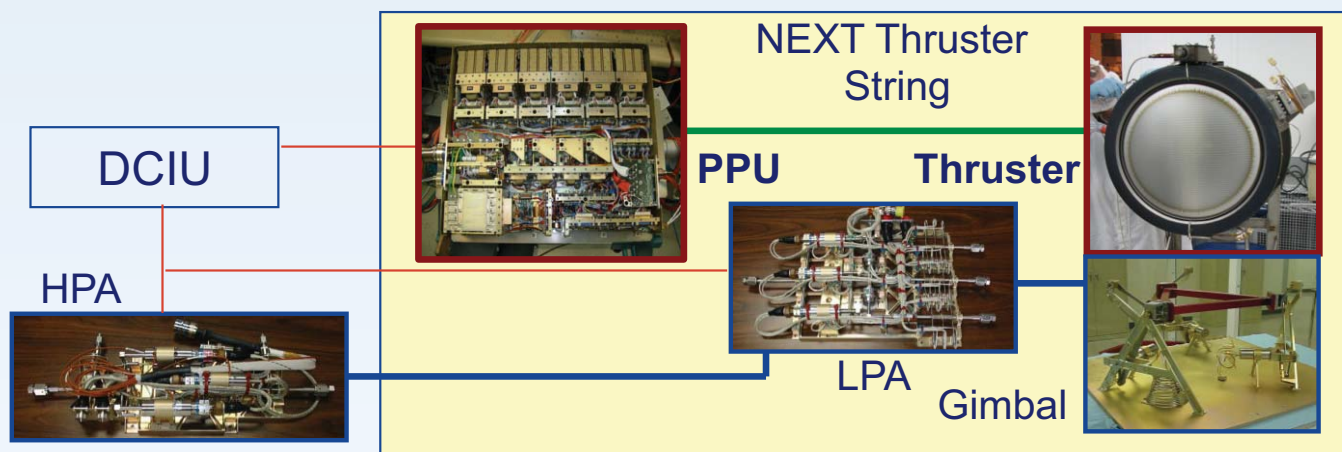
Mission and System Studies



NASA's Evolutionary Xenon Thruster (NEXT)

Expanding SEP Applications For Science Missions

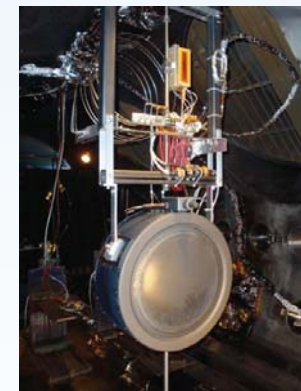
Objective: Improve the performance and life of gridded ion engines to reduce user costs and enhance/enable a broad range of NASA SMD missions



* Rated Capability Goal 300Kg → Design/Qualification Goal (1.5x Rated) 450Kg
Demonstrated Life Limit >900Kg → Potential Rated Capability >600Kg

Characteristic	300	NSTAR (SOA)	NEXT
Thruster Power Range (kW)		0.5= 2.3	0.5-6.9
Max. Thrust (mN)		92	236
Max. Specific Impulse (sec)		>3100	>4100
Max. Thruster Efficiency		>61%	>70%
Total Impulse (x10 ⁶ N-sec)		>5	35.5
Propellant Throughput (kg)		135	918
PPU Specific Mass (kg/kW)		6.0	4.8
PMS Single String Mass (kg)		11.4	5.0
PMS Unusable Propellant Residual		2.40%	1.00%

- NEXT development included critical components for ion propulsion system
- Single-String & Multi-String System Integration Tests completed
- NEXT TRL assessments completed by multiple mission center customers
- Unprecedented diagnostics used for NEXT thruster performance characterization and spacecraft interaction effects testing ongoing
- Thruster and feed system are ready-to-go. 2nd design iteration of PPU being planned.



What the NEXT LDT Demonstrated in 9 yrs of Testing

- NEXT Long Duration Test (LDT) was voluntarily concluded on 1 April 2014

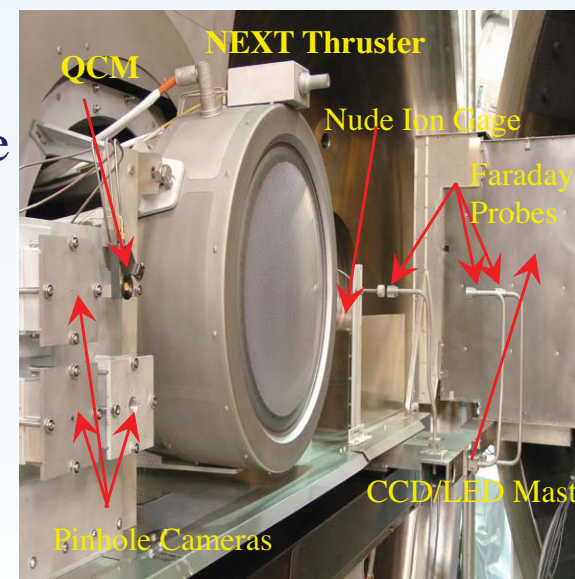
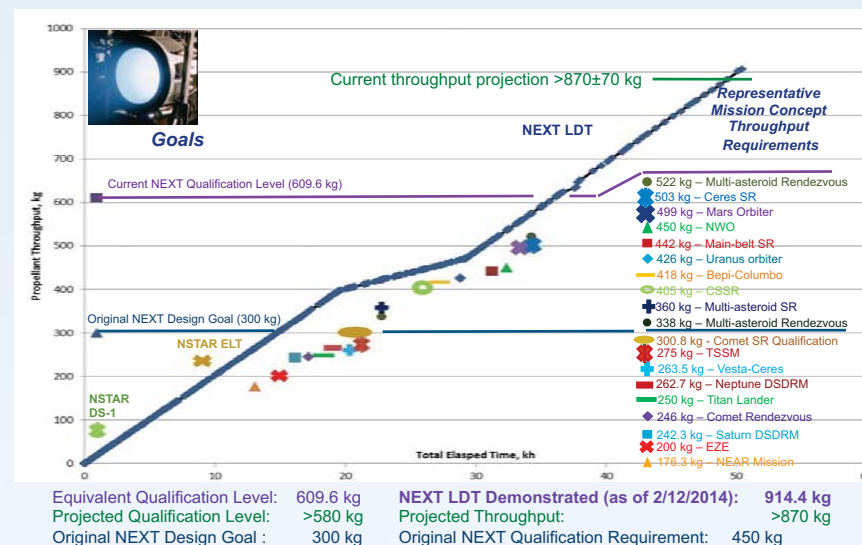
- Collected end-of-test data with repaired and fully functional diagnostic suite to compare with beginning-of-life data
- Post-test inspection and analysis is underway

- The NEXT thruster exceeded design requirements

- Throttle thruster to a deep space mission profile

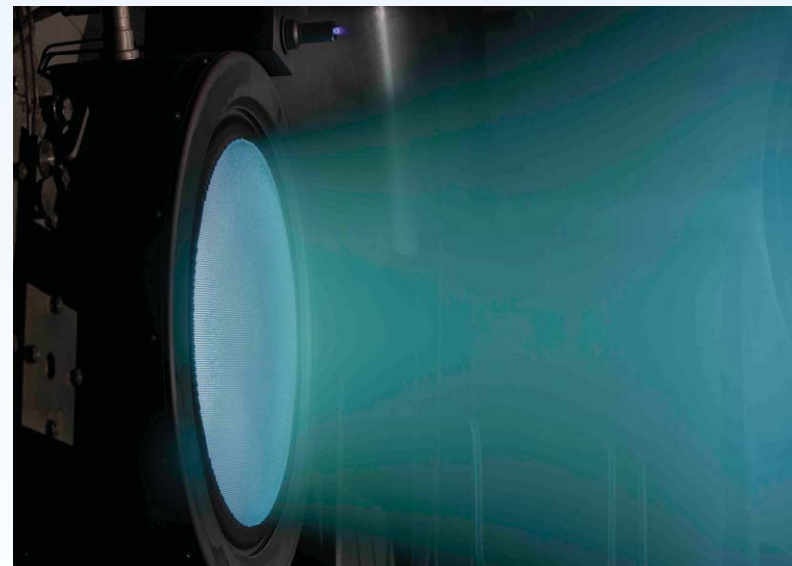
- Goal ≥ 450 Kg qualification level propellant throughput
- Characterized thruster operation over a wide operating table
- NEXT LDT sets Throughput and Duration World Records

- **51,200 hours** of operation
- **918.2 kg Xenon throughput**
- **35.5 MN-s of total impulse** delivered



What the NEXT LDT Demonstrated in 9 yrs of Testing

- Demonstrated that thruster life-limiting phenomena and wear mechanisms associated with ion thruster operations have been addressed in the NEXT design
 - NEXT LDT post-test inspections/analysis will help confirm
- Improved models for future mission planning and operation
 - Compared measured thruster wear rates with those predicted from life models
 - Carbon back-sputter and enhanced charge-exchange facility impact analysis completed
 - Engineering correction factor on wear-rate test results determined
 - <4% reduction for carbon back sputter
 - ~8-10% increase for charge-exchange
- Current Life prediction is 870Kg \pm 70Kg

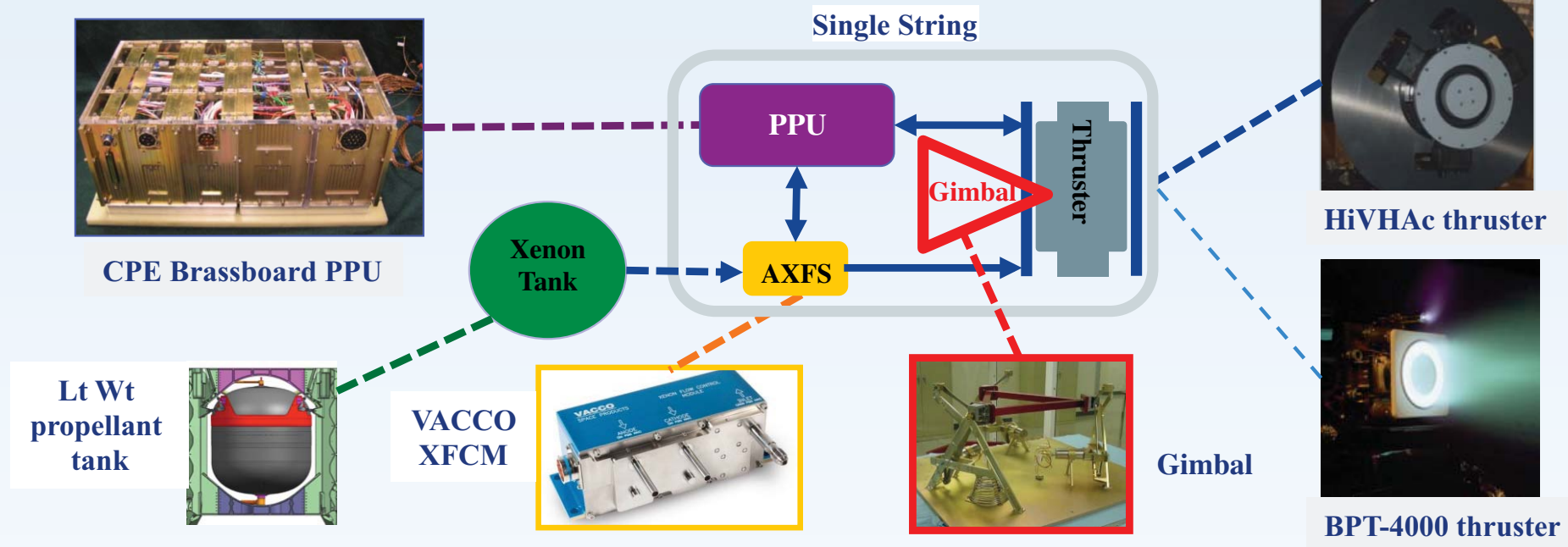


NEXT thruster has exceeded expectations!

High Voltage Hall Accelerator (HIVHAC)

Electric Propulsion for low cost Discovery-class Missions

***Objective:** Develop key components of a HiVHAc Hall propulsion system (thruster, PPU/DCIU, feed system) to TRL 6 to enable/enhance new SMD Discovery missions; expand operational capability to close near-earth mission applications*



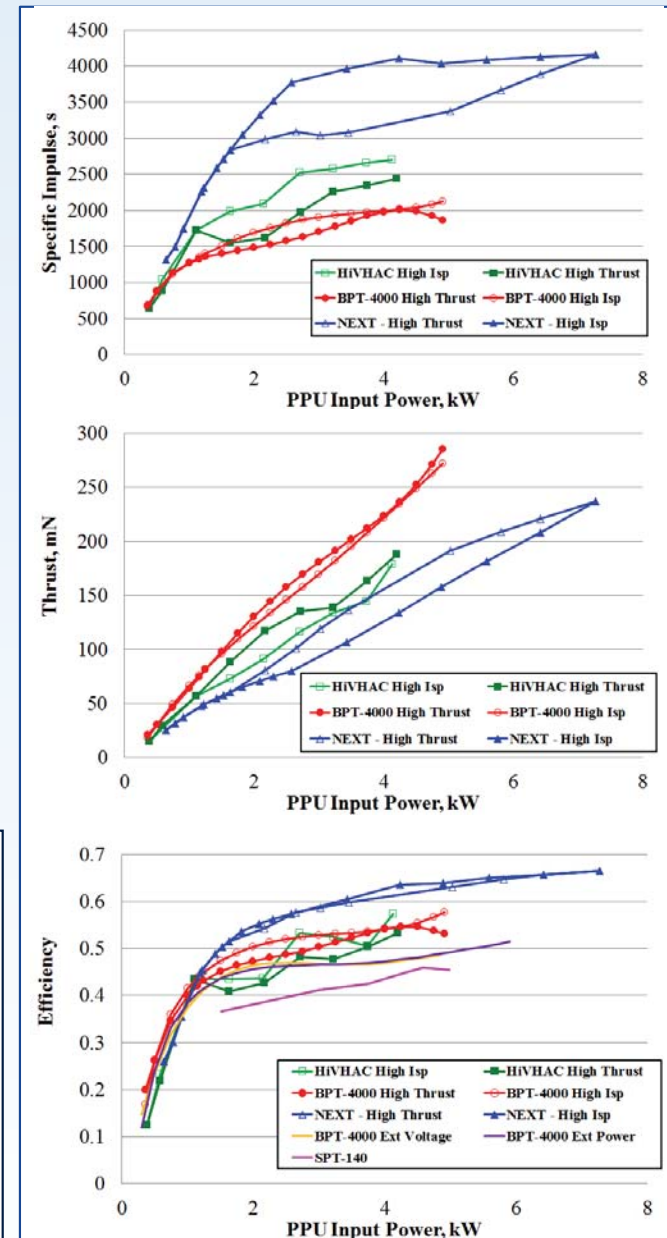
- The HiVHAc thruster offers improved performance and mission benefits over SOA
- Developing a Power Processing Unit (PPU) with a Digital Control Interface Unit (DCIU) to advance the HiVHAc propulsion system readiness
- A flight-qualified Xenon Flow Control Module (XFCM) was delivered to NASA GRC in March 2012 and has been integrated with the HiVHAc thruster. Designed to work with the above PPU.

HiVHAc Development Status

- Testing of the thruster was performed in NASA GRC's Vacuum Facility 5 (VF5) during the Fall of 2013
 - Testing of the thruster was performed at various background pressure conditions
 - Measurements included: performance mapping, plasma mapping, and thermal characterization
- Testing of the EDU2 HiVHAc thruster with a brassboard PPU and the VACCO Xenon Feed System was completed in GRC's VF12 during March of 2014
- A HiVHAc thruster with a modified magnetic circuit was recently tested
 - The discharge erosion starts downstream of the magnetic poles, which protects the poles for a 2 times increase to the projected throughput

Performance Characteristics of HIVHAC vs. SOA Hall (BPT-4000).

Characteristic	BPT-4000	HIVHAC
Thruster Power Range, kW	0.3-4.5	0.3-3.9
Throttle Ratio	15:1	12:1
Operating Voltage, V	150-400	200-700
Specific Impulse, sec	710-2100	860-2700
Thrust, mN	22-260	20-207
Efficiency	0.25-0.58	0.32-0.62
Propellant Throughput, kg	450	>300



Hall Propulsion Power Processing Unit

- PSD's In-Space Propulsion Technology (ISPT) Program has been working with a promising Small Business Innovative Research (SBIR) project to develop a low-cost 4.5-kW class wide output range Hall Power Processing Unit (PPU) for Discovery-class planetary missions.
 - Colorado Power Electronics (CPE) has successfully developed a PPU and is poised to take the design to flight certification (TRL 6) by September 2016
 - Qualification Model (QM) PPU will incorporate control electronics for the PPU power modules, VACCO TRL 7 xenon feed system, and thruster/PPU telemetry
 - CPE has submitted a cost proposal and NASA programs have committed funding to start the effort
- The PPU is being designed to operate several Hall thrusters:
 - NASA's High Voltage Hall Accelerator (HiVHAc), Aerojet-Rocketdyne XR-5 (BPT-4000), Space Systems Loral SPT-140.
 - Thruster acquisition and Hall propulsion system development to be addressed by mission proposal teams.



Ultra Lightweight Tank Technology (ULTT) for future planetary missions

Objective:

- Develop a Composite Overwrapped Pressure Vessel (COPV) tanks for propellants and pressurants for Mars Sample Return (MSR) mission
- To design ultra-lightweight propellant and pressurant tanks sized for Mars Skycrane with an option to manufacture and qualify.

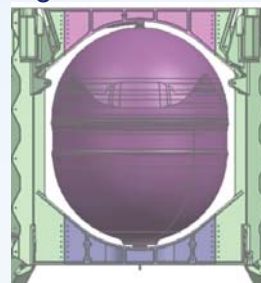
Benefits

- **19.5 kg** mass savings are achievable for 3 tanks sized for the Skycrane (**40% mass reduction**)
 - Mass savings can be passed on to the scientific payload or increase mass margin
- Broad impact to virtually ALL space missions as most use liquid propellants or pressurant
 - Europa Explorer tank mass can be reduced by 60 kg

Accomplishment Status

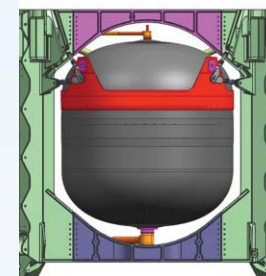
- Critical Design Review CDR) held Feb 2014
- Mars 2020 mission will use build-to-print Skycrane tanks
- Conclude NDI techniques, and no further design or fabrication due to funding limitations and no Mars 2020 adoption

Existing MSL Titanium Tank



594mm Diameter,
~720mm Tall

Drop in replacement ultralight tank



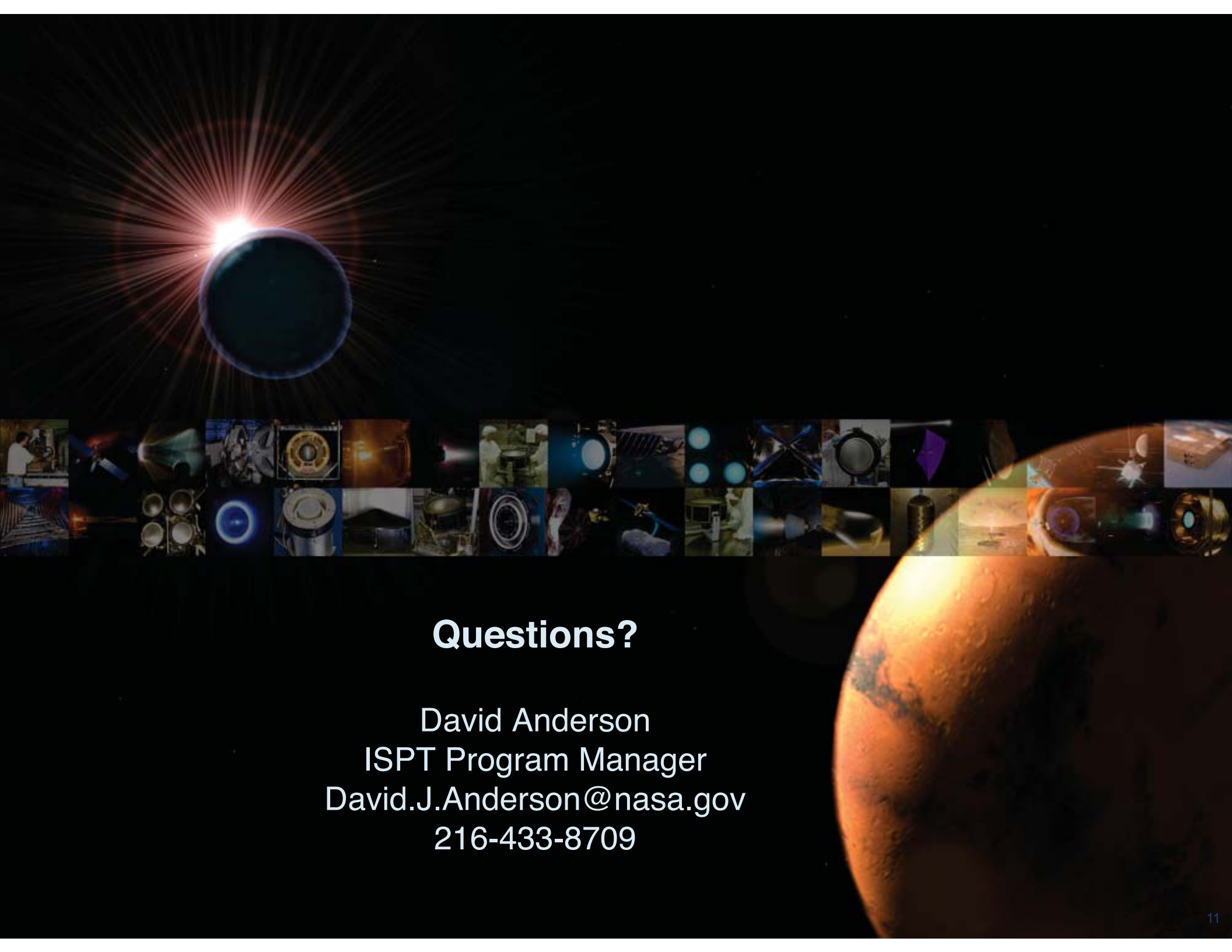
594mm Diameter,
684mm Tall



**Skycrane Descent
Stage Propellant
Tanks**

Summary

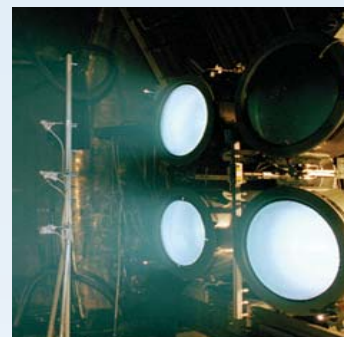
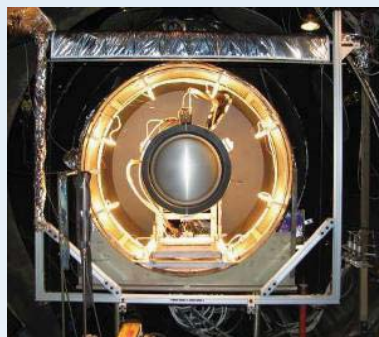
- Concluded NEXT and Ultra-lightweight Tank development
- Concluded NEXT TRL Assessments and Tech Infusion Study, and identified gaps for customer adoption and improve future technology development
- 2014 concludes all ISPT activities. Wrapping up and documenting remaining ISPT work.
 - HIVHAC Thruster development
 - NEXT LDT post-test characterization, inspection, documenting
 - Will continue to support flight infusion
 - NEXT Thruster and PPU may be offered as Government Furnished Equipment (GFE) on upcoming Discovery Announcement of Opportunity
 - 4.5kW Hall PPU development will continue through other funding
- ISPT investments have expanded Planetary Science mission capabilities



Questions?

David Anderson
ISPT Program Manager
David.J.Anderson@nasa.gov
216-433-8709

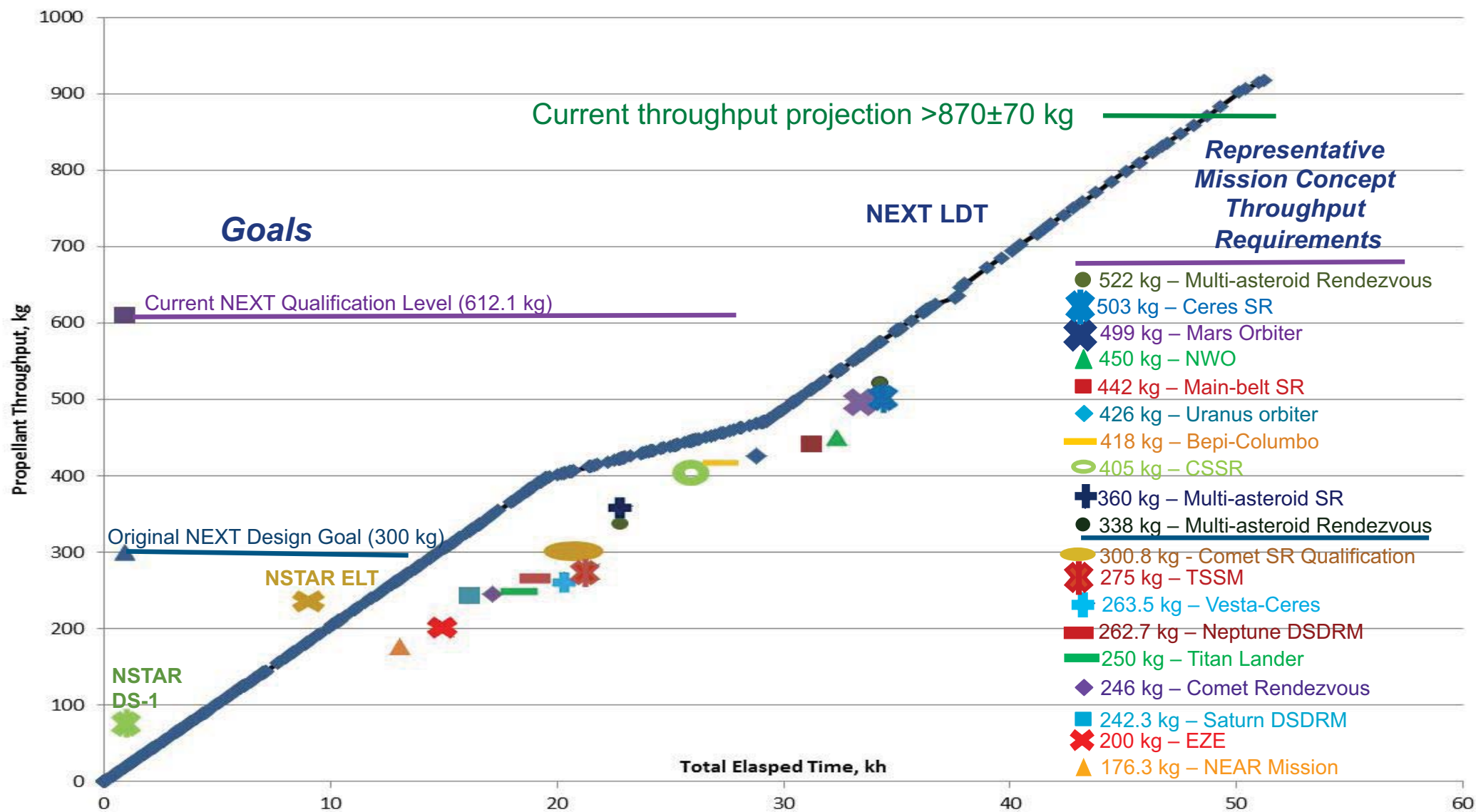
NEXT Mission Benefits & Applicability



CHARACTERISTIC	NSTAR (SOA)	NEXT	Improve- ment	NEXT BENEFIT
Max. Thruster Power (kW)	2.3	6.9	3x	Enables high power missions with fewer thruster strings
Max. Thrust (mN)	91	236	2.6x	
Throttling Range (Max. / Min. Thrust)	4.9	13.8	3x	Allows use over broader range of distances from Sun
Max. Specific Impulse (sec)	3120	4190	32%	Reduces propellant mass, enabling more payload and/or lighter spacecraft
Total Impulse (10^6 N-sec)	4.6	>35.5	>7x	Enables low power, high ΔV Discovery-class missions with a single thruster
Propellant Throughput (kg)	150	918	>4x	

* NOTE: NSTAR used on DS-1 and Dawn missions

NEXT Mission Benefits & Applicability

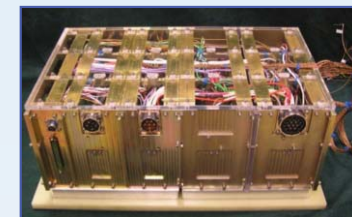


Equivalent Qualification Level: 612.1 kg
 Projected Qualification Level: >580 kg
 Original NEXT Design Goal : 300 kg

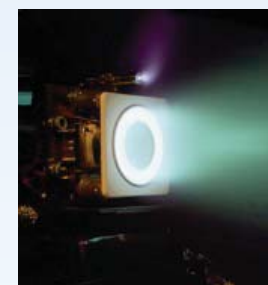
NEXT LDT Demonstrated (as of 3/28/2014): 918.2 kg
 Projected Throughput: >870 kg
 Original NEXT Qualification Requirement: 450 kg

Hall Propulsion Priorities for Planetary Science Missions

- Develop common flight Hall Power Processing Unit (PPU) with capabilities for PSD mission needs for any Hall thruster
 - 5 kW class, modular design
 - Qualify unit and procure 3 flight PPU's as GFE
- Evaluate commercial Hall thrusters (i.e. BPT-4000, SPT-140,...)
 - Delta-qual (as necessary) for PSD environments/life
 - Facility effects assessment and develop ground-test-to-flight-modeling protocols
- Complete the High Voltage Hall Accelerator (HiVHAc) system
 - Assess/incorporate Magnetic Shielding (MS), and qualify thruster
- Leverage STMD's 12-kW Hall system development to address planetary science mission needs
- Maintain Mission analysis capabilities and tool development
 - Community engagement with mission capabilities



PPU



BPT-4000 thruster



HiVHAc thruster

Solar Electric Propulsion Market Options

